

Climate Variability in Ocean Surface Turbulent Fluxes

Mark A. Bourassa, Shawn R. Smith and Eric Chassignet

Center for Ocean-Atmospheric Prediction Studies (COAPS), The Florida State University,
Tallahassee, FL

Project Summary

FSU produces fields of surface turbulent air-sea fluxes and the flux related variables (winds, SST, near surface air temperature, near surface humidity, and surface pressure) for use in global climate studies. Surface fluxes are by definition rates of exchange, per unit surface area, between the ocean and the atmosphere. Stress is the flux of horizontal momentum (imparted by the wind on the ocean). The evaporative moisture flux would be the rate, per unit area, at which moisture is transferred from the ocean to the air. The latent heat flux (LHF) is related to the moisture flux: it is the rate (per unit area) at which energy associated with the phase change of water is transferred from the ocean to the atmosphere. Similarly, the sensible heat flux (SHF) is the rate at which thermal energy (associated with heating, but without a phase change) is transferred from the ocean to the atmosphere. In the tropics, the latent heat flux is typically an order of magnitude greater than the sensible heat flux; however, in polar regions the SHF can dominate.

The FSU activity is motivated by a need to better understand interactions between the ocean and atmosphere on weekly to interdecadal time scales. Air-sea exchanges (fluxes) are sensitive indicators of changes in the climate, with links to floods and droughts (Enfield et al. 2001), East Coast storm intensity (Hurrell and Dickson 2004), and storm tracks (Hurrell and Dickson 2004). On smaller spatial and temporal scales they can be related to the storm surge, and tropical storm intensity. On longer temporal scales, several well known climate variations (e.g., El Nino/Southern Oscillation (ENSO); North Atlantic Oscillation (NAO), Pacific Decadal Oscillation (PDO)) have been identified as having direct impact on the U.S. economy and its citizens. Improved predictions of ENSO phase and its associated impact on regional weather patterns could be extremely useful to the agricultural community. Agricultural decisions in the southeast U.S. sector based on ENSO predictions could benefit the U.S. economy by over \$100 million annually (Adams et al., 1995). A similar, more recent estimate for the entire U.S. agricultural production suggests economic value of non-perfect ENSO predictions to be over \$240 million annually (Solow et al., 1998). These impacts could easily be extended to other economic sectors, adding further economic value. Moreover, similar economic value could be foreseen in other world economies, making the present study valuable to the global meteorological community.

ENSO, PDO, and NAO (AO) each have atmospheric and oceanic components that are linked through the surface of the ocean. Changes in the upper ocean circulation result in modifications to the SST and near surface wind patterns. Variations in SSTs can be related to ENSO and other climate patterns; however, it is the fluxes of heat and radiation near the ocean surface that transfer energy across the air-sea interface. It is an improved understanding of these turbulent fluxes and their variability that motivates our research (radiative fluxes are difficult to accurately estimate from in situ data; however, satellite-based estimates are available). By constructing high quality fields of surface fluxes we provide the research community the improved capabilities to investigate the energy exchange at the ocean surface.

FSU produces both monthly in-situ based and hybrid satellite/numerical weather prediction (NWP) fields of fluxes and the flux-related variables. Our long-term monthly fields are well suited for seasonal to decadal studies, and our hybrid satellite/NWP fields are ideal for daily to annual variability and quality assessment of the monthly products. The flux-related variables are useful for ocean forcing in models, testing coupled ocean/atmospheric models, and for understanding climate related variability (e.g., the monthly Atlantic surface pressure is a good indicator of extreme monthly air temperatures over Florida).

The flux project at FSU targets the data assimilation milestones within the Program Plan. Our assimilation efforts combine ocean surface data from multiple Ocean Observing System networks (e.g., VOS, moored and drifting buoys, and satellites). One set of performance measures targeted in the Program Plan is the air-sea exchange of heat, momentum, and fresh water. When the FSU products are combined with ocean models (either at FSU or other institutes), performance measures relating to surface circulation and ocean transports can be addressed. The FSU flux project also focuses on the task of evaluating operational assimilation systems (e.g., NCEP and ECMWF reanalyses) and continues to provide timely data products that are used for a wide range of ENSO forecast systems. All products are distributed in a free and open manner at: <http://www.coaps.fsu.edu/RVSMDC/FSUFluxes/>.

Accomplishments

Our focus over the past year was the expansion of our research-quality, in-situ monthly Atlantic and Indian Ocean products to include the turbulent fluxes. Through this process several data problems were identified and corrected. These products have been compared to a select set of flux and satellite products. In summer 2006, we began developing a the FSU3 flux product for the Pacific Ocean. We also continued our operational production of monthly quick-look wind fields for the tropical Pacific and Indian Oceans. All products are available on a new web site which also includes methods for tracking data users.

Global and Regional satellite stress products have continued to improve through more effective use of rain-flagged (suspect) observations. Preliminary validation of our in situ wind products in comparison to satellite wind products indicate excellent similarity. Formal analysis of uncertainty was delayed when we discovered biases in the NCDC TD-1129 data set lead to biases in our flux products. These biases were corrected through use of the ICOADS data set. We have been working on bias correction of NWP temperature and moisture data, which will be used in our satellite/NWP flux products. We have also improved blending of satellite and a NOAA tropical cyclone analysis product (H*WIND), which was used in a study identifying the cause of a storm surge far greater than the NOAA prediction (Morey et al. 2006). That study lead to a change in NOAA prediction of storm surges, which should prevent this type of error in future forecasts.

Deliverables for FY 2006 included:

1. Complete 1978-present research-quality 1° in situ wind and flux analyses for Atlantic, Indian, and Pacific Oceans (north of 30°S)
 - Subtask 1: Reduce regional and temporal biases in the in situ FSU winds and Fluxes, and improve estimates of random error.

- Subtask 2: Reprocess 1998-2004 fields based on expected release of new ICOADS data set
 - Subtask 3: Reduce regional biases in the tropics
- 2. Continue operational production of quick-look winds for tropical Pacific and Indian oceans
- 3. Complete variability analysis of 1978-present 1° analyses for tropical Pacific, Indian, and Atlantic Oceans
- 4. Evaluate methods for extending tropical Pacific and Indian Ocean fields prior to 1978
- 5. Extend development of uncertainty fields to cover fluxes
- 6. Calculate wind uncertainty fields for completed ocean basins
- 7. Continue comparisons of FSU winds and fluxes to available products
- 8. Produce global (over water) satellite fields scalar winds and fluxes
- 9. Develop an objective technique for assessing periods for temporal averaging of satellite data.
- 10. Produce and distribute products containing surface turbulent and radiative fluxes

Production of research quality 1° in-situ fluxes [Deliverable 1]

Over the past year we completed the 1978-2004 1° wind and flux products for the Atlantic Ocean (north of 34°S) and the Indian Ocean (north of 30°S). Examples of these monthly products, known as the FSU3 (version 3.0 of the Bourassa objective method; Hughes et al. 2006), are provided in Figures 1 and 2. During this process, we discovered that using the NCDC TD-1129 marine observations for 1998-2004 resulted in a discontinuity in the wind and flux products, as well as an error that increased with time. The reasons for this are beyond the scope of our investigations. In Fall 2005, the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) project released version 2.2 of their product. The product included a full update of the 1998-2004 period, so we decided to replace the NCDC data with the ICOADS and reprocessed the FSU winds and fluxes. This required additional man hours to be allocated to the Indian and Atlantic products. The resulting ICOADS based products did not exhibit the same discontinuity that appeared in the version using the NCDC data, and the winds were an excellent match to satellite observations (which are an excellent comparison data set). The ICOADS-based products are now being distributed to the community (see below).

The downside of reprocessing the 1998-2004 period for the Atlantic and Indian oceans is that it delayed our work on a 1° product for the Pacific Ocean and our formal error analysis. Analysis of the tropical and North Pacific began in summer 2006 and is 40% complete for the period 1978-2004.

Production of in-situ quick-look products [Deliverable 2]

An older version (the FSU2) of the Bourassa et al. (2005) objective method continues to be applied to create two-degree tropical Pacific Ocean wind (pseudo-stress) fields based on in-situ data. Quick-look two-degree gridded pseudo-stress fields are produced at the beginning of each month using the previous month's GTS-transmitted data. In addition to the Pacific, COAPS continues to produce one-degree pseudo-stress fields for the tropical Indian Ocean using the method of Legler et al. (1989). Related research quality products exist through 2004 for the Pacific and 2003 for the Indian Ocean. We have not updated the FSU2 and Legler research products as we had anticipated switching to the Bourassa 3.0 method. This switch was delayed by the problems discovered with the NCDC data. We anticipate the switch to occur once the 1°

FSU3 product is completed for the Pacific. Both two-degree fields for the Pacific Ocean and one-degree fields for the Indian Ocean FSU winds are available at <http://www.coaps.fsu.edu/RVSMDC/SAC/index.shtml>.

Complete variability analysis of 1978-present 1° analyses for tropical Pacific, Indian, and Atlantic Oceans [Deliverable 3]

Atlantic Ocean fluxes have been completed; Indian Ocean fluxes have been completed for 1978 through October 2006; and Pacific Ocean fluxes are still being processed (40% complete for the ‘modern period’). We have completed a preliminary analysis of variability in the Atlantic (Hughes 2006) and Indian (Banks 2005) Oceans for the available periods.

Evaluate methods for extending tropical Pacific and Indian Ocean fields prior to 1978 [Deliverable 4]

This deliverable was dependent on developments from NASA supported activities, for which funding has been delayed for more than a year.

Extend development of uncertainty fields to cover fluxes [Deliverable 5]

The conceptual framework on uncertainties has been extended to fluxes. The mathematical formulas have been determined, and some of the coding has been completed.

Calculate wind uncertainty fields for completed ocean basins [Deliverable 6]

This task appears to be nearly completed. It was delayed due to the man-hours lost in resolving the issues associated with the subtle flaws in the NCDC TD-1129 data set. We have compared satellite and in situ winds for the QSCAT observational period. The satellite observations are an excellent standard of comparison; therefore, this study resulted in good estimates of uncertainty and biases for that period. These results will be ideal for evaluating the technique we are developing to estimate uncertainty directly from in situ observations.

Continue comparisons of FSU winds and fluxes to available products [Deliverable 7]

We found large difference in winds and particularly surface turbulent fluxes among the products that we compared: FSU3, NOC, WHOI, and NCEPR2. Due to the problems with the NCDC TD-1129 data set, we focused much of our attention to comparisons between the above products and satellite winds (which have less observational uncertainty and much better sampling). The FSU3 and NOC products were very good matches to satellite winds (winds are not included in the WHOI product). Nevertheless, there were large differences in NOC and FSU3 energy fluxes. These differences could be due to either flux algorithms or biases in temperatures and humidities.

Produce global (over water) satellite fields scalar winds and fluxes [Deliverable 8]

This product is dependent on completion of bias corrections in NWP temperatures and humidities. That evaluation was delayed due to the man-hours lost in resolving the issues associated with the subtle flaws in the NCDC TD-1129 data set. We have acquired the data sets to be used in this comparison.

Develop an objective technique for assessing periods for temporal averaging of satellite data [Deliverable 9]

This objective is dependent on the completion of the objective determination of uncertainties (deliverable 6), which was delayed due to the man-hours lost in resolving the issues associated with the subtle flaws in the NCDC TD-1129 data set.

Completion of FSU Flux web page [Deliverable 10]

A new distribution web site for the FSU Fluxes is now available (<http://www.coaps.fsu.edu/RVSMDC/FSUFluxes/>). The web site provides an overview of the FSU Flux project and User Notes allow the community to make an informed choice about which FSU products (in-situ or satellite/NWP) would best serve their research needs. Access is provided for all scatterometer products, the FSU3, and all older versions of the FSU fluxes and winds. Links to publications resulting from the FSU winds and flux project and technical documentation are provided. New to flux pages is an extensive catalog of “Related Products”. This page includes links to available in-situ, satellite, and blended flux products, NWP products, high latitude fields, ocean analyses and wave products, and in-situ flux validation data. The products catalog was produced in response to a need put forward by the World Climate Research Program Working Group on Surface Fluxes.

New to the FSU Flux page is a user tracking tool. When a user first accesses the “In-Situ Fluxes” link on the page, they are asked to enter some basic user contact information (the system is modeled on one used by the National Center for Atmospheric Research Data Support Section). The user’s email address is collected and is used as their password for future access to the data site. There are no restrictions on who can access the data, the information collected simply allows us to track our user community. The information is stored in a database and allows the data center to contact users with updates and information related to the FSU Flux products. As of 1 November 2006, we have 24 registered users from 7 countries (Brazil, China, France, Germany, India, U.S., and the UK).

Publications and Reports

Refereed

- Bourassa, M. A. , 2006: Satellite-based observations of surface turbulent stress during severe weather. *Atmosphere - ocean interactions, Vol 2.*, W. Perrie, Wessex Institute of Technology, 35-52.
- Kara, A. B., J Metzger, M. A. Bourassa, 2006: Ocean Current and Wave Effects on Wind Stress Drag Coefficient and Fluxes over the Global Ocean. *Geophys. Res. Letters*, accepted.
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- Banks, R. F., 2005: Variability of Indian Ocean surface fluxes using a new objective method. M.S. Thesis, 43, Tallahassee, FL, USA.

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- Hughes, P. J., M. A. Bourassa, J. Rolph, and S. R. Smith, 2006: Interdecadal Variability of Surface Heat Fluxes Over the Atlantic Ocean. *CAS/JSC Working Group on Numerical Experimentation, Research Activities in Atmospheric and Oceanic Modeling*, World Meteorological Organization, ed. J. Côté, 2:17-18 pp.
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Figures

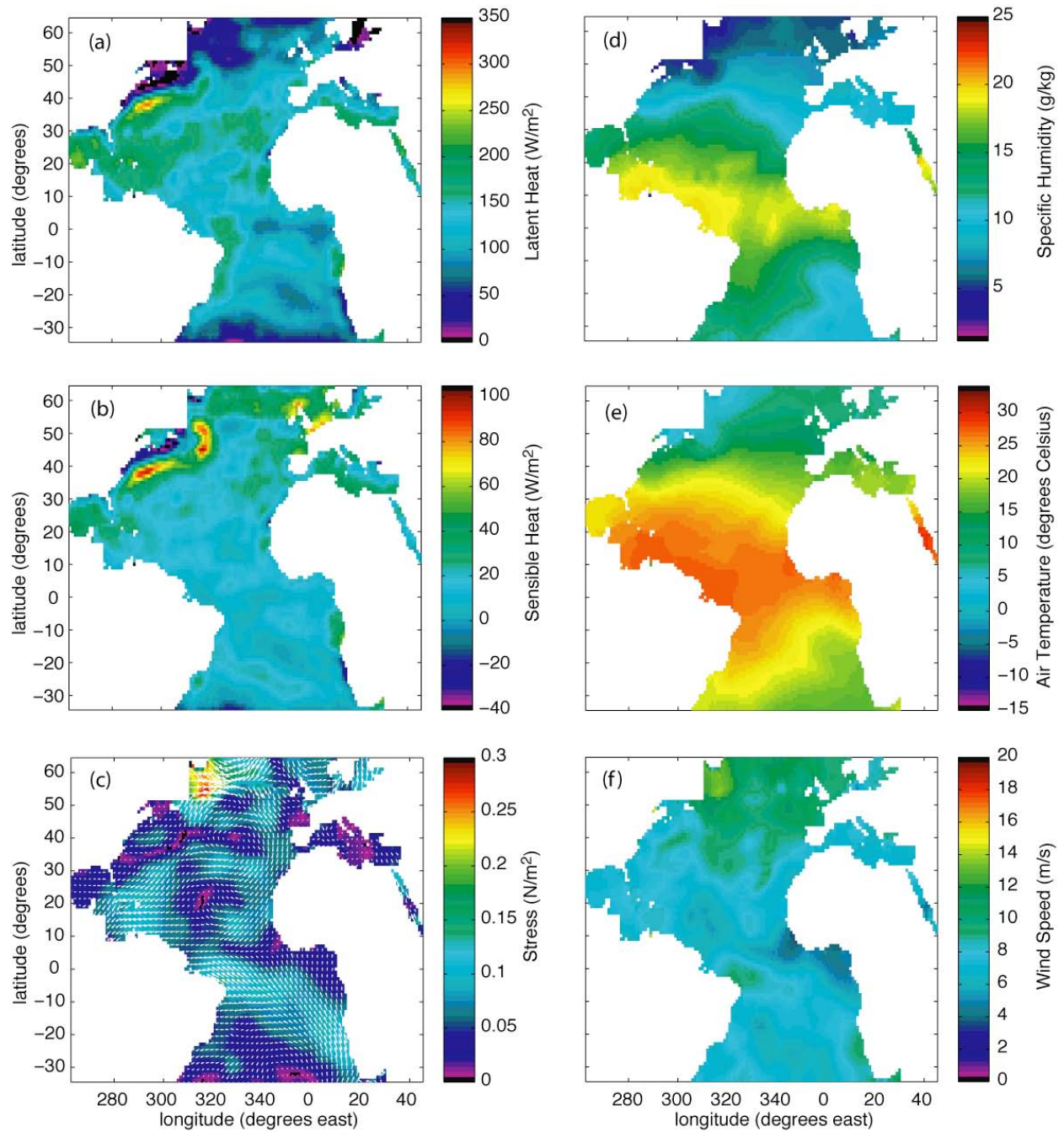


Figure 1. Atlantic Ocean FSU3 flux products for November 2005: (a) latent and (b) sensible heat flux, (c) momentum flux (wind stress), (d) 10 m specific humidity, (e) 10 m air temperature, and (f) 10 m wind speed. Scales and units are noted in the color bars.

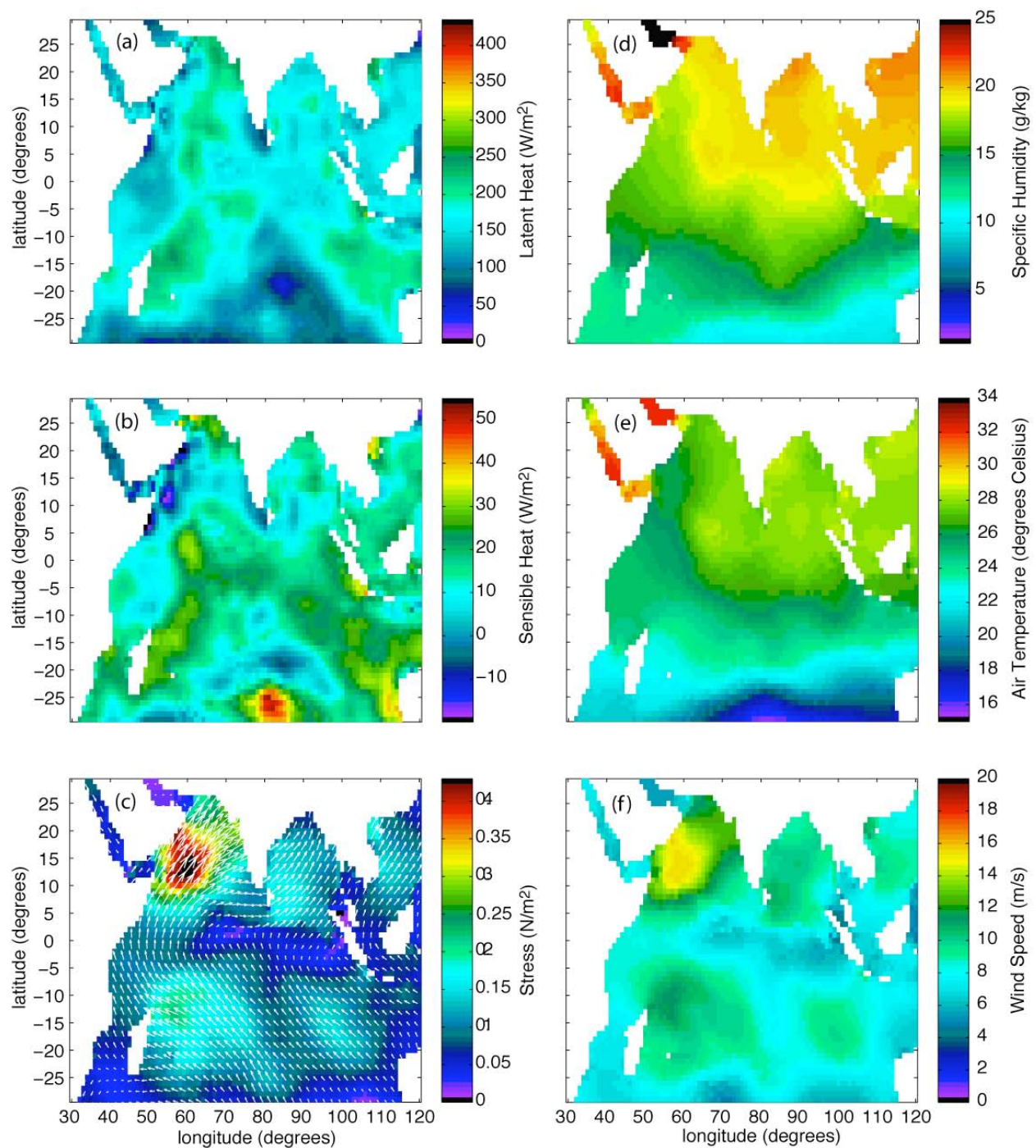


Figure 2. Indian Ocean FSU3 flux products for July 2006: (a) latent and (b) sensible heat flux, (c) momentum flux (wind stress), (d) 10 m specific humidity, (e) 10 m air temperature, and (f) 10 m wind speed. Scales and units are noted in the color bars.